Metaheuristic approach based Intelligent Relay Coordination study for Power System Protection

Mrs.P.Rohini Krishna Chaitanya[1] Dr. P Suresh Babu[2]

[1] Assistant Professor EEED, St.George Institiue of Engineering & Technology Markapur, e-mail: chaitupeddi84@gmail.com

[2] Assistant Professor EED, National Institute of Technology Warangal, e-mail: drsureshperli@nitw.ac.in

***Abstract*— Relay coordination is important for maintaining proper power system operation and control. Relays should be organized in a special way such that every relay should have a backup and Coordination Time Interval (CTI) between primary and back up and different zones of the relay should be maintained to achieve proper fault identification and fault clearance sequences. The relays should operate in minimum desirable time satisfying all the coordination constraints optimally hence it is a highly constraint problem. Heuristic techniques are often used to get optimal solution of this kind of problems. In order to ensure reliable protection and better relay coordination, proper Time Multiplier Setting (TMS) and type of relay characteristics selection for the fault current has targeted in this work. Proposed methodology was tested with 6 bus power system with proper arrangement of Distance relay and Overcurrent relay using metaheuristic optimization methods and selection of TMS values was presented. Based on speed of convergence the best suited optimization algorithm for the above mentioned task also mentioned.**

***Keywords— Coordination of relay; Coordination time interval; Teaching learning based optimization; Plug setting; Time setting multiplier; Over current relay characteristics, GA,PSO, TLBO*.**

I. Introduction

Relays should be organized in such a way that every relay should have a backup and CTI between primary and back up and different zones of the relay should be maintained. Relay co-ordination is essential to achieve proper fault identification and fault clearance sequences. During fault conditions, these relays must operate quickly isolating the faulted section of the network and allow the continuous operation of the healthy part of the circuits. If primary relay desired for clearance of the fault fails, backup relay must operate after providing a sufficient time gap for the operation of primary relays. Hence the operation of back up relays must be coordinated with the operation of the primary relays. The flexible settings of the relays (e.g- plug setting, Time multiplier setting and possibly selection of suitable time-current operating characteristics), must be set to achieve the desired objectives.

Over current and distance relays are often used together for protection of power system. Now a days this scheme is used in almost all sub-transmission systems. To achieve better coordination, a distance relay with another distance relay, an over current relay with another over current relay and an over current relay with a distance relay must be coordinated. One of them will act as main relay and another one will act as back up relay. Proper co-ordination time interval must be maintained between them.

The study of co-ordination of relays was first done among over current relays. Initially it is done by using linear programming method including simplex, two-phase simplex and dual simplex methods [1]-[4]. But the problem associated with these methods is the solution can not be obtained unless all the constraints are satisfied.

So, people gradually started to use intelligent and Meta–heuristic approaches which gives optimal solution instead of exact solution meeting all the constraints criteria optimally. In ref.[5], optimal co-ordination is done by Genetic Algorithm. Ref.[6] shows optimal coordination by using Particle swarm optimization and Ref.[7] shows the time coordination by using evolutionary algorithm. But these schemes are having two types of problems. First one is mis-coordination and other one is lack of solution for relays with both discrete and continuous time multiplier setting (TMS). These problems are resolved in [8] by adding a new expression with the objective function. All the above discussed methodologies are done by using over current relays and the relay characteristics are assumed to be fixed. While in digital relays different over current relay characteristics can be selected. So, the algorithm for relay coordination should be capable of selecting the best fitting characteristics of over current relays to have optimal coordination.

Ref.[9] shows relay coordination with an hybrid GA algorithm which is helpful in relay coordination of over current and distance relays. Ref.[10] shows relay coordination using GA and intelligent relay characteristics selection. Ref. [13]-[15] shows relay coordination using TLBO for small systems but all of them used fixed characteristics (Standard IDMT). No attempts were made to utilize different intelligent characteristics available in digital relays.

In this paper, Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Teaching Learning Based Optimization (TLBO) algorithms were used to study distance and over current relay coordination with intelligent over current relay characteristics selection. A comparative analysis of the results obtained from TLBO with the same obtained from GA and PSO is presented in results section. TLBO is found to be simpler and reliable than other mentioned two algorithms.

II. Teaching Learning based optimization (TLBO)

TLBO is an algorithm inspired by teaching learning process. It is proposed by Rao et al. [11]. The learning process will be done through two stages such as teacher stage and learner stage. While modeling the algorithm, the group of learners was modeled as population; subjects opted by learners were modeled as design variables. Here, learners result becomes the fitness value. After iteration, the best solution inside the population becomes teacher and the constraints of optimization problem become design variables [11]-[18].

A. Teacher Stage

The first stage is the teacher stage. As it is well known teacher teaches students and increases the mean depending upon their capability. Assume that there are 'm' number of subjects (i.e. design variables), 'n' number of learners (i.e. population size, k = 1,2,..., n) and the mean result of the learners is $M_{j,i}$ in a particular subject 'j' (j = 1,2,..., m). The best overall result considering all the subjects together obtained in the entire population of learners can be considered the result of the best learner, k_{best}. However, since the teacher is usually considered a highly learned person who trains learners so that they can have better results, after iteration, the best learner will be considered as teacher. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by

$$Difference\_Mean_{j,k,i} = r_i(X_{j,kbest,i} - T_F M_{j,i}) \quad (1)$$

Where $X_{j,kbest,i}$, is the result of the best learner (i.e., teacher) in subject j. T_F is the teaching factor, which decides the value of the mean to be changed, and r_i is the random number in the range [0, 1]. The value of T_F can be either 1 or 2. The value of T_F is decided randomly with equal probability as follows:

$$T_F = round[1 + rand(0,1)\{2-1\}] \quad (2)$$

T_F is not a parameter of the TLBO algorithm. The value of T_F is not given as an input to the algorithm, and its value is randomly decided by the algorithm using Eq. (2). After conducting a number of experiments on many benchmark functions, the algorithm was concluded to perform better if the value of T_F was between 1 and 2. However, the algorithm was found to perform much better if the value of T_F is either 1 or 2. Hence, the teaching factor is suggested to take a value of either 1 or 2 depending on the rounding up criteria given by Eq.(2) to simply the algorithm. Based on the $Difference\_Mean_{j,k,i}$, the existing solution is updated in the teacher phase according to the following expression:

$$X'_{j,k,i} = X_{j,k,i} + Difference\_Mean_{j,k,i} \quad (3)$$

Where $X'_{j,k,i}$ is the new value of $X_{j,k,i}$. Accept $X'_{j,k,i}$ if it improves the value of the function. After teacher stage, all fitted values will be given as input to the learner stage. So, it means the learner stage depends on teacher stage.

B.Learner Stage

Learner phase is the second part of the algorithm. Learners boost up their knowledge by interacting among themselves. A learner learns new things if the other learner has more knowledge than him or her. Considering a population size of '*n*', the learning phenomenon of this phase is expressed below.

Randomly select two learners *P* and *Q* such that X'_{total}-*P,i* ≠ *X'total-Q,i* (where, *X'total-P,I* and *X'total-Q,i* are the updated values of *Xtotal-P,i* and *Xtotal-Q,i* respectively at the end of teacher phase)

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}), If\ X'_{total-P,i} < X'_{total-Q,i} \quad (4)$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}), If\ X'_{total-P,i} > X'_{total-Q,i} \quad (5)$$

Accept $X''_{j,P,i}$ if it gives a better function value.

III.GENETIC ALGORITHM (GA)

Genetic Algorithm (GA) is a very well-known meta-heuristic algorithm which mimics the biological process of reproduction by human gene. GA uses the principles of genetic evolutions and natural selections such as selection rate, cross over and mutation etc [8-10]. The steps of GA can be summarized as follows:

***i) Initialization**:* Populations are randomly initialized and then set them as search space. Then their fitness is calculated by calculated their values by objective function.

ii) Evolution: Then an offspring pool is created via applying genetic operators such as selection, cross over and mutation. Mutation rate is very small (such as 0.01 to 0.1).Whereas selection or cross over rate will be relatively higher (0.5-0.8).

iii) Fitness calculation: Evaluate the fitness value of the generated off-springs.

iv) Convergence check: Check whether the termination criteria is satisfying or not. If not then repeat from the evolution process otherwise terminate (if termination criteria is satisfied). The common termination criteria for GA are, solutions found to fulfil criteria; fixed number of generations reached; computation time set or money allocated for it reached; successive iterations are no longer capable to produce better results; combinations of the previous discussed issues.

GA are largely used in various research areas to generate very high quality solutions to many optimization and search problems.

IV.PARTICLE SWARM OPTIMIZATION (PSO)

PSO is a swarm intelligent based optimization technique mimics from swarming behaviors of animals and social behavior of human. The PSO works on having a population (Swarm) of candidate solutions (particles). The particles movement will be guided by their own known best position as well as the entire swarm's known best position. When better positions are discovered then that have effect on movement of the swarms. By this process the satisfactory solutions are eventually be discovered. Each particle's velocity and position in the next iteration can be described by the following equations [6-7]:

$$V_i(t+1) = w(t)V_i(t) + C_1 r_1(P_i(t) - X_i(t+1)) + C_2 r_2(G_i(t) - X_i(t+1)) \quad (6)$$

$$X_i(t+1) = X_i(t) + \lambda V_i(t+1) \quad (7)$$

Where, w(t) is inertia coefficient or weight which varies from 0.4-0.9. λ is constriction factor. Here it is 0.7. C_1 and C_2 are cognitive and social parameters respectively. Both values are set to be 2 here. r_1 and r_2 are random real numbers between 0 and 1. P_i denotes the positional best and G_i denotes the global best. X_i denotes position.

V.PROBLEM STATEMENT

For achieving better protection, it is common to use both distance and over current relays as main and back up relays respectively, in power transmission protection schemes. In this situation, it is necessary to coordinate these two types of relays simultaneously that makes the problem harder to find a global operating point.

$$Fitness\ function = \min(\alpha\sum_{i=1}^{n} t_i + \beta\sum_{i=1}^{n}\left|T_{DIOCi} - \left|T_{DIOCi}\right|\right| + \lambda\sum_{i=1}^{n}\left|T_{OCDIi} - \left|T_{OCDIi}\right|\right| + \delta\sum_{i=1}^{n}\left|T_{OCi} - \left|T_{OCi}\right|\right|) \quad (8)$$

Where

$$T_{OCi} = T_{ocbackupi} - T_{ocmaini} - CTI' \quad (9)$$

$$T_{DIOCi} = T_{oci} - T_{z2i} - CTI' \quad (10)$$

$$T_{OCDIi} = T_{z2i} - T_{oci} - CTI' \quad (11)$$

T_{oc} is the operating time of over current relay and Tz2 is the operating time of 2nd zone of the distance relay $\alpha, \beta, \lambda, \delta$ are penalty factors.

VI. CONSTRAINTS

The several constraints need to be satisfied to obtain optimal co-ordination and settings are as follows:

A. Co-ordination constraints

$$T_{z2backup} - T_{ocmain} \geq CTI' \quad (12)$$

$$T_{ocmain} - T_{z2backup} \geq CTI' \quad (13)$$

CTI is coordination time interval whose typical value is between 0.2 to 0.3 sec.

B. Relay Characteristics

The over current relay characteristics are typically of below nature:

$$t = TSM\left(\frac{K}{M^{\alpha} - 1} + L\right) \quad (14)$$

t= time of operation of the relay
TSM= Time setting multiplier.
K, L and α are constants. It varies characteristics to characteristics.
M is the ratio between short circuit current I_{sc} and pick up current I_p

TSM is supposed to be continuous and can take any value between 0.05-1.1. Coordinating time interval in each cases is supposed to be 0.25 sec. Eight types of intelligent over current relay characteristics are obtained from Ref.[10].

C. Pick-up current constraints

Pick up current having a limit. The relay co-ordination problem is highly dependent on the value of the pickup current of the relays. To sense a small amount of fault current the pickup current should be less than minimum fault current. On the other hand the minimum pick up current may be doubled under small overloaded condition to avoid any mal-operation. The limits of pick up current can be expressed as below [15]:

$$Ip_{\min} \leq Ip \leq Ip_{\max} \quad (15)$$

D. TSM constraints:

TSM is supposed to be continuous and can take any value between 0.05-1.1. Mathematically it can be expressed as below

$$TSM_{\min} \leq TSM \leq TSM_{\max} \quad (16)$$

E. Constrains on relay operating time

For minimizing or mitigating mal-operation due to transient, overshoot or any other critical condition of the network, relays should operate after a minimum time. Limits on time of operation of relay(t_{op}) can be expressed as :

$$t_{op\min} \leq t_{op} \leq t_{op\max} \quad (17)$$

Minimum operation time of relay is 0.1 sec and maximum depends on the requirement of the user.

VII. TEST RESULTS

To test the methodology a 6 Bus system has been selected. The relay arrangements are shown for this power system as same as it is shown in Fig1. The mho directional relays are used here. The different kinds of intelligent over current relay characteristics used in digital relays are obtained from Ref.[10]. Main and back up relay pairs with short circuit data are shown in Table-I.

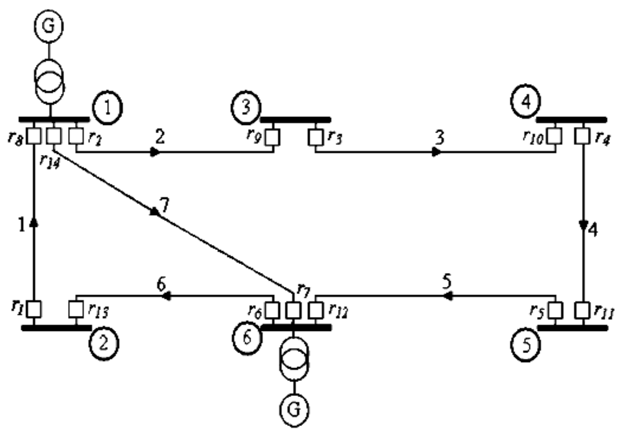

Fig.1: 6 Bus Power System with Relay arrangement

Table-I: Main and backup relay pairs with short circuit data

Main Relay(r_M)	Back up Relay(r_B)	Main relay short circuit current(Amp)	Back up relay short circuit current(Amp)
r_2	r_1	5428	828
r_{14}	r_1	4184	816
r_3	r_2	3505	3505
r_4	r_3	1769	1769
r_5	r_4	1103	1103
r_6	r_5	4936	340
r_7	r_5	4184	337
r_1	r_6	2682	2682
r_2	r_7	5428	1571
r_8	r_7	4933	1563
r_{13}	r_8	2492	2492
r_8	r_9	4933	340
r_{14}	r_9	4184	337
r_9	r_{10}	1174	1174

r_{10}	r_{11}	2589	2589
r_{11}	r_{12}	3655	3655
r_7	r_{13}	4184	816
r_{12}	r_{13}	5431	828
r_6	r_{14}	4936	1565
r_{12}	r_{14}	5431	1573

The typical operating time of first, second and third zones of all distance relays have been 20ms, 0.3sec (or more) and 0.6 sec (or more) and all points of starting second zones of all lines are 80% of the lines. The short circuit currents of the main and back up over current relays must be calculated from close in bus fault cases (Critical fault locations). The information regarding pick up current settings are shown in Table-II. The value of pick up current of each over current relay is assumed roughly 1.25 times of the relevant maximum load in approximated integer form. Total number of relays used here is 14. From Table-I, it is found that relays r_2,r_6,r_7,r_8,r_{12},r_{14} are having better protection reliability compare to other relays, as they have more than one backups.

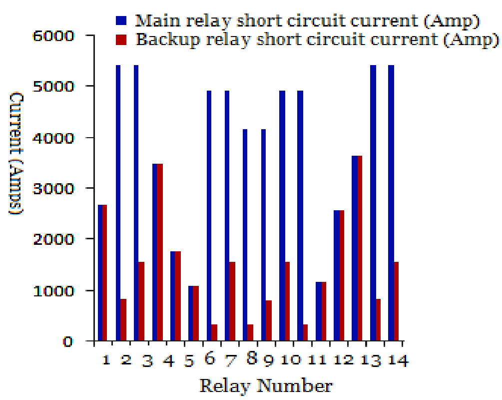

Fig.2: Comparison of short circuit currents of main and backup relays

Table-II: Pick up current values of the Relay

Relay number(r_i)	Load Current(Amp)	Pick up Current(Amp)
r_1	104	125
r_2	166	200
r_3	125	150
r_4	180	200
r_5	129	137
r_6	114	137
r_7	141	162
r_8	109	137
r_9	118	135
r_{10}	110	137
r_{11}	135	162
r_{12}	122	137
r_{13}	125	150
r_{14}	166	200

The process of finding objective function is trial and error. The ultimate target of choosing the objective function is to reduce the time of operation of relays, same as in the case of over current to over current relay co-ordination case. The only difference here is some additional terms are coming due to the presence of distance relay. When $|T_{DIOCi}|$ is positive then the second term of objective function is becoming zero but when $|T_{DIOCi}|$ is negative then the second term is additive with the objective function and increasing its value. Since it is a minimization problem, the chance of survival of such fitness value is mitigated by this approach. As per co-ordination constraints $|T_{DIOCi}|$ value should be always greater than equals to zero. Its value can be negative only in case of mis-coordination. So, with such approach the chance of mis-coordination problem is almost nullified. The same kind of explanation can be given for choosing the third and fourth terms of the fitness function also.

By applying TLBO (Teaching learning based optimization) in the network of Fig1 the output results are obtained. TSMs and over current relay characteristics selected by TLBO are shown in Table-III. In all cases TSMs are considered to be continuous (0.05-1.1). The time of operation of relays in each case are also shown in the table (Table-III). The various outputs from this work are shown pictorially from Fig.2 to Fig.5.

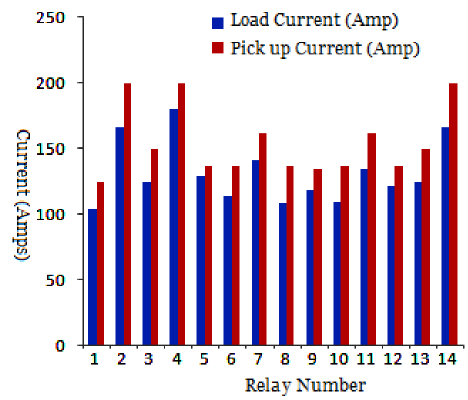

Fig.3: Comparison of Load current and pick up current of various relays

Table-III: TMS and type of Characteristics selection

Relay (r_i)	Second Zone operation time (T_{z2})(sec)	TSM	No. of selected Characteristic
1	0.537	0.242567	2
2	0.4987	0.243110	2
3	0.5482	0.254736	2
4	0.6027	0.191837	3
5	0.5333	0.162270	3
6	0.5693	0.302211	2
7	0.4984	0.239195	2
8	0.5806	0.308156	2
9	0.537	0.169566	3
10	0.6233	0.269546	6
11	0.5872	0.269727	2
12	0.5365	0.292676	2
13	0.5333	0.220228	2
14	0.4942	0.221336	2
Average Value	0.54855	0.24194	-
Fitness value	120.664		

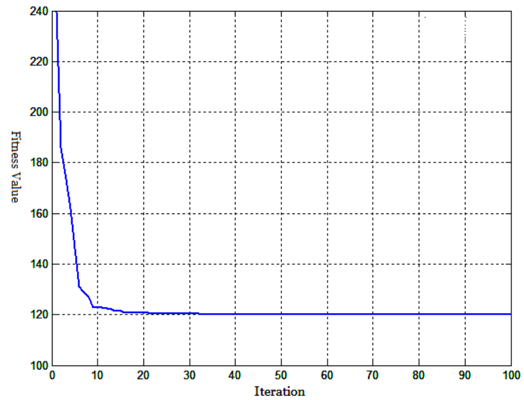

Fig.4: Convergence curve of the TLBO algorithm

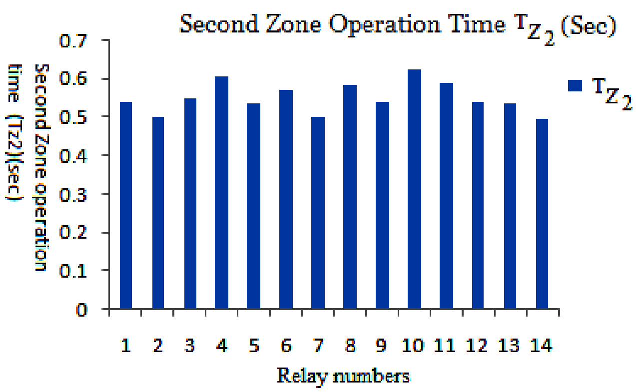

Fig.5: Comparison of operating time of second zone of relays

VIII. DISCUSSIONS

TLBO does not have any algorithm specific control parameter for finding global optimum solution like other algorithms which is a tremendous advantage over other contemporary optimization techniques. GA (Genetic Algorithm) uses mutation rate, selection rate and cross over probability. PSO (Particle Swarm Optimization) uses inertia weight, social and cognitive parameters. The proper tuning of these parameters are very important for the performance of these optimization algorithms. TLBO does not need such kind of parameters. It only needs population size and number of generations for working. So, TLBO becomes highly consistent optimization algorithm. It converges very fast and superior compare to GA and PSO. Table –IV and Table-V enlists the comparison of results for our problem by using GA, PSO and TLBO [10].

Table-IV: Comparison of TMS values obtained by using GA,PSO and TLBO

Relay (r_i)	**TMS Values obtained from GA**	**TMS Values obtained from PSO**	**TMS Values obtained from TLBO**
1	1.641	0.351708	0.242567
2	0.851	0.387488	0.243110
3	1.629	0.364677	0.254736
4	0.872	0.218295	0.191837
5	0.723	0.204275	0.162270
6	0.998	0.530754	0.302211
7	1.518	0.479925	0.239195
8	1.037	0.430754	0.308156
9	0.785	0.215766	0.169566
10	1.420	0.332449	0.269546
11	2.000	0.359345	0.269727
12	2.000	0.345528	0.292676
13	1.390	0.312954	0.220228
14	0.050	0.247867	0.221336
Average Value	1.208	0.341556	0.24194
Fitness value	125.000	124.635	120.664

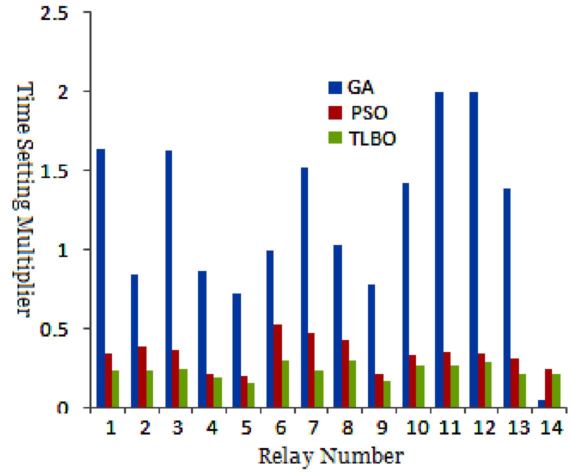

Fig.6: Comparison of optimum Time setting multipliers of relays obtained by GA, PSO and TLBO

From Table-IV and Fig.6, it is clear that the results obtained by GA are sometimes violating the range with context to TSM (r_1, r3, r7, r10, r_{11}, r_{12}, r_{13}) for the particular case taken for study and the average value of TSM is also out of maximum specified range. Whereas PSO and TLBO results are within range. TLBO is giving least average TSM value and least fitness value. The convergence curve obtained by GA and PSO algorithms are shown in Fig.7 and Fig.8. Comparison of the results obtained by GA, PSO and TLBO with respect to process speed is shown in Table –V.

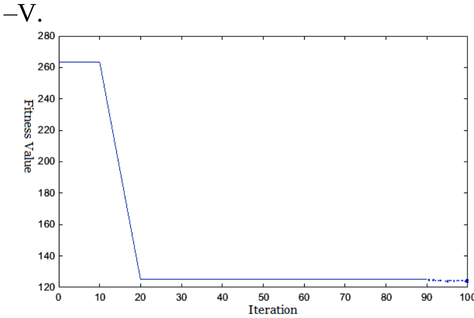

Fig.7: Convergence curve using Genetic Algorithm (GA)

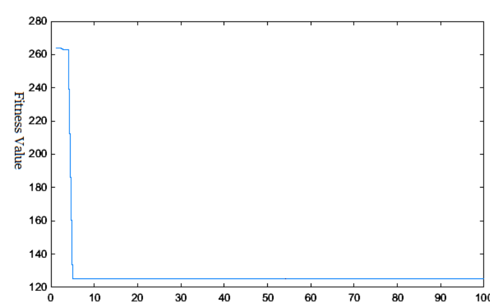

Fig.8: Convergence curve using Particle Swarm Optimization (PSO)

Table-V: Comparison of results obtained by using GA, PSO and TLBO with respect to process speed

Attributes	GA	PSO	TLBO
Number of iterations to converge	20	8	16
Average time per iteration(Sec) taken	0.00955	0.0304	0.00438
Total time taken to converge (CPU elapsed time)(sec)	0.191	0.243	0.07

PSO is taking more time than GA although number of iterations for convergence are less. Because PSO needs three types of updating while performing one iteration. i.e. Velocity updating (here fitness value), position updating (here TMS values) and g_{best} , P_{best} updating. So, time taken for one iteration is more in case of PSO than GA. But among these three algorithms TLBO is converging in least CPU elapsed time as per Table-V. Here the simulation is done on PC with processor: Intel®core (TM) i7-2350 M CPU@2.30GHZ, RAM: 8.00 GB and MATLAB R 2015b.

IX. CONCLUSIONS

This paper focused on optimal co-ordination of directional and over current relays. The problem statement and various constraints to be satisfied are already presented in the paper. Teaching learning based optimization (TLBO), which is a modern meta-heuristic technique is applied to solve the problem. The optimum time of operation, TSM, pick up currents of relays are calculated for a 6 bus system. All the constraints are found within desirable range. Which intelligent over current characteristics are required to get the desired result are also selected. The obtained results from TLBO are compared with the results obtained from GA and PSO and required analysis is done which was the main objective of our work. The protection settings seems to be satisfactory for the discussed power network. The technique is working satisfactorily with respect to other contemporary techniques like GA and PSO also. As a future extension of this work, relay coordination on higher test systems can be implemented.

APPENDIX

The test system data obtained from Ref.[10].

REFERENCES

[1]. A. J. Urdaneta, R. Nadira, and L. G. Perez "Optimal coordination of directional overcurrent relays in interconnected power system" *IEEE Transactions on Power Delivery*, Vol. 3, No 3, Jul.1998.

[2]. A. J. Urdaneta, H. Resterpo, J. Sanchez, and J. Fajardo, "Coordination of directional overcurrent relays timing using linear programming," *IEEE Transactions on Power Deivery.*, vol. 11, no. 1, pp. 122–129, Jan. 1996.

[3]. B. Chattopadhyay, M. S. Sachdev, and T. S. Sidhu, "An on-line relay coordination algorithm for adaptive protection using linear programming techniques," *IEEE Transactions on Power Deivery.*, vol. 11, no. 1, pp. 165–173, Jan. 1996.

[4]. H. Askarian Abyaneh and R. Keyhani, "Optimal co-ordination of overcurrent relays in power system by dual simplex method," presented at *the AUPEC Conference*, Perth, Australia, 1995

[5]. C. W. So, K. K. Li, K. T. Lai, and K. Y. Fung, "Application of genetic algorithm for overcurrent relay coordination," in *Proceedings of Instrumentation Electrical Engineering Conference Developments in Power System Protection*, Mar. 25–27, 1997, pp. 66–69.

[6]. H. Zeineldin, E. El-Saadany, and M. A. Salama, "Optimal coordination of overcurrent relays using a modified particle swarm optimization," *Electric* Power *System Research.*, vol. 76, no. 11, Jul. 2006.

[7]. C. W. So and K. K. Li, "Time coordination method for power system protection by evolutionary algorithm," *IEEE Transactions on Industrial Applications*, vol. 36, no. 5, pp. 1235–1240, Sep./Oct. 2000.

[8]. F. Razavi, H. Askarian Abyaneh, M. Al-Dabbagh, R. Mohammadi, and H.Torkaman, "A new comprehensive genetic algorithm method for overcurrent relays coordination," *Electric* Power *System Research.*, vol. 92, no. 9, Apr. 2008.

[9]. J.Sadeh, V.Aminotojari and M.Bashir ," Optimal coordination of over current and distance relays with hybrid genetic algorithm", in proceedings of *10th International conference on Environment and Electrical Engineering*, IEEE,Rome, Italy,8-11 May,2011.

[10]. R.M. Chabanloo , H.A.Abyanch, SS.H.Kamangar and F.Razavi," Optimal combined overcurrent and distance relays coordination incorporating intelligent overcurrent relay characteristics selection", *IEEE Transactions on Power Delivery,* Vol.26, No.3,pp.1381-1391, July 2011

[11]. R.V.Rao and G.G.Wagmare ," A comparative study of a teaching–learning-based optimization algorithm on multi-objective unconstrained and constrained functions*", Journal of King Saud University- Computer and Information Sciences,*Vol.26,pp. 332-346, Dec. 2013.

[12]. R.V.Rao and V.Patel," An elitist teaching-learning-based optimization algorithm for solving complex constrained optimization problems" *International Journal of Industrial Engineering Computations,* Vol.3, pp.535-560, March 2012.

[13]. M.Singh, B.K.Panigrahi and A.R.Abhyankar, "optimal coordination of directional over-current relays using teaching learning-based optimization(TLBO) algorithm", *Electrical Power and Energy Systems,* Vol.50,pp.33-41, March 2013.

[14]. A.A.Kalage and N.D.Ghawghawe ," Optimum coordination of directional overcurrent relays using modified adaptive teaching learning based optimization algorithm", *Intelligent Industrial System* , Vol.2, Issue 1,pp.55-71, March 2016.

[15]. D.Saha , A.Dutta , B.K.Saha Roy and P.Das," Optimal coordination of DOCR in interconnected power systems", Presented in *IEEE 2nd International Conference on Control, Instrumentation, Energy and Communication*,28-30 Jan.,2016, Kolkata, India

[16]. M.Ojaghi and R.Ghahremani," Piece–wise linear characteristic for coordinating numerical overcurrent relays", *IEEE Transactions on Power Delivery*, Vol.32,No.1,pp.145-151, February 2017.

[17]. R.V.Rao,V.J.Savsani and J.Balic," Teaching–learning-based optimization algorithm for unconstrained and constrained real-parameter optimization problems", *Engineering Optimization*, Vol.44, No.12,pp.1447-1462, Dec. 2012.

[18]. R.V.Rao ," Review of applications of TLBO algorithm and a tutorial for beginners to solve the unconstrained and constrained optimization problems ", *Decision Science Letters*, Vol.5, Issue1,pp.1-30, March 2016.